HEP Theory Group
Oct. 2012–Dec. 2012 Quarter Activities

Top Quark Rapidity Asymmetries

During the 4th Quarter of 2012, Ed Berger and collaborators continued their studies of the forward-backward asymmetries A_{FB}^t and A_{FB}^ℓ in the top quark t rapidity distribution and in the rapidity distribution of charged leptons ℓ from top quark decay. These asymmetries are observed at the Tevatron proton-antiproton collider, and a charge asymmetry A_C is seen in proton-proton collisions at the Large Hadron Collider (LHC). In a long paper submitted to Physical Review D, E. Berger, in collaboration with Argonne postdoctoral fellow Hao Zhang and former postdoctoral fellows Qing-Hong Cao and Chuan-Ren Chen, updated their previous studies of the Tevatron asymmetries using the most recent data. In their recent work, they provided expectations for A_C at the LHC based first on simple extrapolations from the Tevatron results, and second based on new physics models that can explain the Tevatron asymmetries. They also examined the relationship of the two asymmetries A_{FB}^t and A_{FB}^ℓ, and they showed their connection through the $(V-A)$ spin correlation between the charged lepton and the top quark with different polarization states. Furthermore, they showed that the ratio of the two asymmetries provides independent insight into the physics interpretation of the top quark asymmetry. Considering the value of the measurement of both asymmetries, they concluded that a model which produces more right-handed than left-handed top quarks is suggested by the present Tevatron data. An Appendix includes a detailed analytic derivation of the spin correlation between the charged lepton and the top quark with different polarization states.

Quarkonium Production

During this period, G. Bodwin made progress in understanding the collinear and infrared singularity structure of quarkonium fragmentation functions and NRQCD quarkonium matrix elements. These insights are steps toward an all-orders proof of NRQCD factorization for inclusive quarkonium production, which, if achieved, would have a major impact on analyses of results from col-

lider experiments. Also during this period, G. Bodwin prepared a conference proceeding (with Hee Sok Chung and Jungil Lee) on Endpoint Logarithms in $e^+e^- \to J/\psi + \eta_c$ (submitted to the arXiv in January 2013) and an erratum (with Andrea Petrelli) on Order-v^4 Corrections to S-Wave Quarkonium Decay (submitted to the arXiv in January 2013). The conference proceeding is the first presentation of results that identify for the source of large double logarithms in calculations of the cross section for $e^+e^- \to J/\psi + \eta_c$ at the B factories. Insights that were obtained in this work may lead to methods for all-orders resummation of these and other, related large logarithms.

Higgs Boson Production

Radja Boughezal, Frank Petriello and Markus Schulze have provided the differential cross-section for Higgs boson production in gluon fusion in association with a hadronic jet at next-to-next-to-leading order (NNLO) in perturbative QCD. This result is urgently needed in order to reduce the theoretical uncertainties hindering a precise extraction of the Higgs properties at the LHC. Currently, the theoretical errors in the one-jet bin comprise one of the largest systematic errors in Higgs analyses at the LHC, particularly in the WW final state. They have shown explicitly how to employ known soft and collinear limits of scattering amplitudes to construct subtraction terms for NNLO computations. The NNLO QCD corrections significantly reduce the residual scale dependence of the cross-section. The computational method that they described in their paper is applicable to the calculation of NNLO QCD corrections to any other $2 \to 2$ process at a hadron collider.

F. Petriello, in collaboration with Liu in the HEP theory group studied the resummation of a large class of Sudakov logarithms affecting Higgs production in bins of exclusive jet multiplicity. This computation, as the one described above, is essential to produce the reliable results necessary in experimental analyses of Higgs searches.

Higgs Boson Signatures

Current Higgs data at the Large Hadron Collider is compatible with a SM signal, but until recently the central value of the signal strength in the diphoton channel seemed to be enhanced with respect to the SM expectation at both experiments. As Carlos Wagner and collaborators showed in pre-

vious 2012 publications, if the enhancement resides in the diphoton partial decay width, the data, it could be accommodated in the Minimal Supersymmetric Standard Model (MSSM) with highly mixed light staus (I. Low and C. Wagner further demonstrated the general properties that new particles must fulfill in order to enhance the Higgs diphoton decay rate). I. Low and C. Wagner, in collaboration with M. Carena, from Fermilab, S. Gori from the University of Chicago and N. Shah from the University of Michingan, revisited the issue of vacuum instabilities induced by large mixing in the stau sector, including ffeffects of a radiatively-corrected tau Yukawa coupling. While the metastability of the Universe constrains the possible enhancement in the Higgs to diphoton decay width in the light stau scenario, an increase of the order of 50% can be achieved in the region of large $\tan\beta$. Larger enhancements may be obtained, but would require values of $\tan\beta$ associated with non-perturbative values of the tau Yukawa coupling at scales below the GUT scale, thereby implying the presence of new physics beyond the MSSM.

C. Wagner, in collaboration with students G. Lee and R. Huo from the University of Chicago and postdoc A. Thallapillil from Rutgers (former student at Chicago) studied an extension of the Minimal Supersymmetric Standard Model with a gauge group $SU(2)_1 \times SU(2)_2$ breaking to $SU(2)_L$. The extra wino has an enhanced gauge coupling to the SM-like Higgs boson and, if light, has a relevant impact on the weak scale phenomenology. The low energy Higgs quartic coupling is modified by new contributions to its renormalization group evolution from high energies. This leads to interesting regions of parameter space in which the model can accommodate a 125 GeV Higgs with relatively light third generation squarks and an increased $h \to \gamma\gamma$ decay branching ratio, while still satisfying the constraints from electroweak precision data and Higgs vacuum stability.

Searches for ttbar plus Missing Energy Signatures at the LHC

Radja Boughezal and Markus Schulze studied the pair production of scalar top-quark partners decaying to a top-quark pair plus large missing energy at the LHC, a signature which appears in numerous models that address outstanding problems at the TeV-scale. In all experimental searches so far performed, the signal process was modeled with leading-order kinematics, and was normalized to an inclusive higher-order prediction for stable stops.

The severe experimental search cuts require a description which combines production and decay dynamics for a realistic final state. An exact next-to-leading order (NLO) QCD analysis was not performed, nor were NLO QCD corrections considered in the decay of the top partner, or in the decay of the top quark. Radja and Markus have done this at NLO in QCD for the first time. They found large, kinematic-dependent QCD corrections that differ dramatically depending upon the observable under consideration, potentially impacting the search for and interpretation of these states. Their new results are crucial to assist in both the search for and eventual interpretation of the underlying model assuming discovery.

Motivated by the prospects of finding light stops at the LHC, Ian Low has been working on polarization issues in the stop searches at this collider.

Formal Physics

Abstract work on neutrinos and umbral structures in fundamental processes has also been carried out by Cosmas Zachos and collaborators. The second edition of a book on phase-space, substantially expanded and now titled "A Concise Treatise on Quantum Mechanics in Phase Space" has been submitted to Imperial Press and is currently under production.